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The Analysis of Applications of Micro-flux Control Drilling Technology in Narrow Density Window Drilling Scenarios

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Abstract

Drilling in narrow window is complex. Drilling accidents like kick, loss, collapse and stuck often occurs. MPD technology can effectively solve these problems. Micro-flux control technology ,one style of MPD technology, has the advantage of simple structure, low costs and greatly enhancing the ability of well control. This paper focuses on research of the micro-flux controlled drilling technology. It includes structure, principle, control mechanism and application. Practice has proved that micro-flux controlled drilling technology can effectively solve the problems triggered by complex situations and ensure the safety of drilling.

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Keywords: narrow density window; micro-flux; security window; pressure; well control;

1. Main text

With the continuous development of petroleum exploration and development to the complex and deep formation, drilling safety issues of narrow window become increasingly prominent. In many areas of oilfields, it has become the technical bottlenecks in drilling, such as the Tarim Basin, South Xinjiang, Qingxi in Yumen, Sichuan Basin and Qaidam Basin, etc [1]. The drilling problems of narrow window have become the main cause of long drilling cycle,

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frequent accidents, the down-hole complex problems in deep and ultra-deep wells, high temperature and high pressure wells in water and on land, it is an urgent problem [2].

1. The concepts and hazards of narrow density window

Narrow density window is usually defined as that the annulus pressure loss is greater than or equal to the difference between pore pressure and fracture pressure in the process of drilling, which gives challenges to the options of drilling fluid density and drilling security. the result is that, if the annulus hydrostatic pressure is less than the pore pressure , an overflow will occurs [3]; and when the drilling fluid circulate in the borehole, bottomhole pressure is greater than the formation fracture pressure, an loss will occurs. To solve the problem of narrow window drilling safety is to solve the drilling security issues, such as, kick, loss, collapse, kick and loss in the same layer, overlying kick and underlying loss, and kick and loss in the same time.

In the actual drilling process, leakage and overflow are often opposite to each other on the surface, and they are both relevant to drilling liquid flow. therefore the most direct way to deal with leakage and overflow in the conventional drilling technology is to observe, measure the liquid level of the drilling mud tanks rising or falling; or if there is drilling fluid returning to the wellhead or not in the stop drilling period. If it dose return, overflow may has occured. If not, it means maybe drilling normally or drilling with dropout. But the results obtained by direct observation are probably not a true reflection of the downhole conditions. E.g., wellhead fluids Spillover may be due to aggravating inequality [4]; standpipe pressure dropping may be due to the drilling rig washout; standpipe pressure rising may be due to the clogging of the bit port; bubbles in the drilling fluid may be caused by treating chemical [5]. And when the leakage or overflow is found relying on the traditional way, the capacity has been relatively large, it can't be solved quickly, efficiency is low, and safe hazards has existed.

Conventional drilling technology has been unable to deal with the complex issues caused by narrow density window. At present, the most effective way is to use MPD technology, an advanced technology. MPD technology can achieve balanced drilling or near balanced drilling after determining the bottom-hole pressure window, by adjusting the wellhead back pressure to precisely control the annular pressure profile, so that the entire wellbore pressure is maintained between the pore pressure and fracture pressure to solve the drilling problem[6].MPD technology can be divided into micro-flux control technology (MFC) and DAPC. Currently we mostly use DAPC . MFC is now rarely used and poorly studied. Compared to DAPC, the micro-flux control technology has many advantages, such as a more simple structure, less using time ,lower cost and improving the well control capabilities. It also can reduce the layer number of casing, reduce drilling costs and improve drilling efficiency [7],so that it is very suitable for drilling a narrow density window formation.

2. The micro-flux control technology

MFC only make some changes to the traditional drilling rig[8], drilling crew can quickly meet the drilling technology requirements in the ground through a simple operation, prevent and solve the drilling accidents; MFC achieve the purpose of pressure control by commanding micro drilling fluid flow, which is different with DAPC on the control principle. We install precise sensor and drilling fluid reducer In the drilling fluid circulation pipe, which can real-timely monitor and forecast many parameters of the drilling liquid at the entrance and exit ,e.g. micro pressure, mass flow, equivalent circulating density and flow rates. This technology can accurately detect parameters of drilling fluid, e.g. the mass flow rate, density, viscosity, the temperature, which can detecte less than 80L kick and control the overflow of within 2min[9], so that the total volume of the overflow is less than 800L. MFC accomplish controlled pressure drilling by means of micro flow control principle and technology and it doesn't need PWD tools, so saving drilling cost to some extent. MFC can precisely control the bottom-hole pressure, effectively deal with drilling difficulties that is overflow or leakage in the fracture pressure sensitive formation with the narrow window even without the safe density window[10], achieve the safe drilling.

2.1 The main structure of MFC equipment

The basic structure of MFC includes rotating control device, micro-flux chock manifold, data acquisition and control system, a gas-liquid separator, pressure control drilling room, back pressure pump and pipeline ,etc. Data

acquisition and control system is the heart of the system, and carry out specific control through the micro-flux chock manifold.

(1)Rotating control device(RCH)

Rotating control device is one of the main MPD equipments,which is the key supporting equipment of closed circulation system under pressure and the dynamic annular pressure control system[11]. Low pressure rotating control device is the most common design for gas drilling, high pressure rotating control device is the most common design for Liquid UBDand MPD. The RCH technology is more mature and has more types In foreign countries, mainly include RCH of USA Williams company, RCH of Sea-Tech company , Shaffer RCH of Varco company, the expanded capsule of Canadian alpine company.

(2)micro-flux chock manifold

Micro flow choke manifold is a key component of the MFC technology, it has the advantages of small volume, convenient installation; the intelligent control unit [12].It can automatically and continuously regulate back pressure with high precision, control manually,have the high accuracy volumetric displacement meters and accurately measure and obtain the flow rates, temperature and density of drilling fluid backflow. Its main function is to adjust the wellhead back pressure through exchanging the degree of opening of the Automatic throttle valve on the Choke manifold ,and finally achieve the purpose to control the bottom hole pressure.

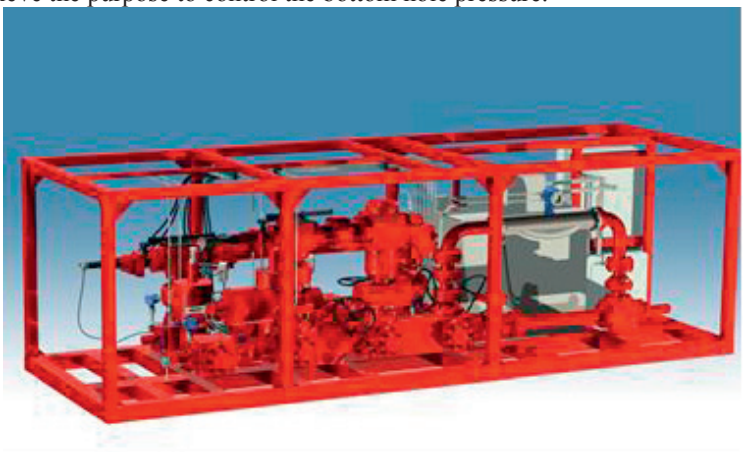

Fig.1 PCDS-1 micro-flux choke manifold

PCDS-1 precise managed pressure drilling system was developed by CNPC drilling research institute,which has the function of MFC.Now we will introduce the choke manifold of PCDS-I as an example.The design pressure is 35 MPa [13].Throttle skid is mounted with a Coriolis mass flowmeters and several precise pressure sensor,which can accurately survey several parameters of the circulating fluid. the choke manifold of PCDS-I can realize automatic control through the intelligent control unit, and is provided with a set of real time data acquisition and control system.

(3)Data acquisition and control system

The data acquisition system consists of sensors, the intelligent control module, server, terminal control panel. The intelligent control module is the brain of the pressure control system and responsible for the collection and analysis of data, which can control the choke manifold. The server is responsible for storing the data. Terminal control panel includes an operator panel, control panel and remote browsing panel. The operator can set and control the whole system by the panel [14].

In general, that MFC technology achieve the aim of managed pressure drilling is based on the real-time monitoring parameters including the micro pressure, mass flow, equivalent circulating density, velocity, etc. The drilling engineering personnel can quickly change the performance of drilling fluid through a simple operation on the ground, that can meet the requirement of the drilling technology, prevent and resolve drilling accidents. The control procedure is simple to operate, can switch with the conventional drilling method and improve the drilling efficiency and drilling safety.

2.2The drilling process of MFC

Micro-flux control drilling system by installing micro-flow sensor and bean choke on the traditional ground drilling fluid circulating line to achieve real-time monitoring the drilling fluid pressure, flow, equivalent circulating density, velocity and other parameters, at the same time realize feedback control, ultimately attain the purpose of managed pressure drilling. Here is a simple process as shown in figure 3.

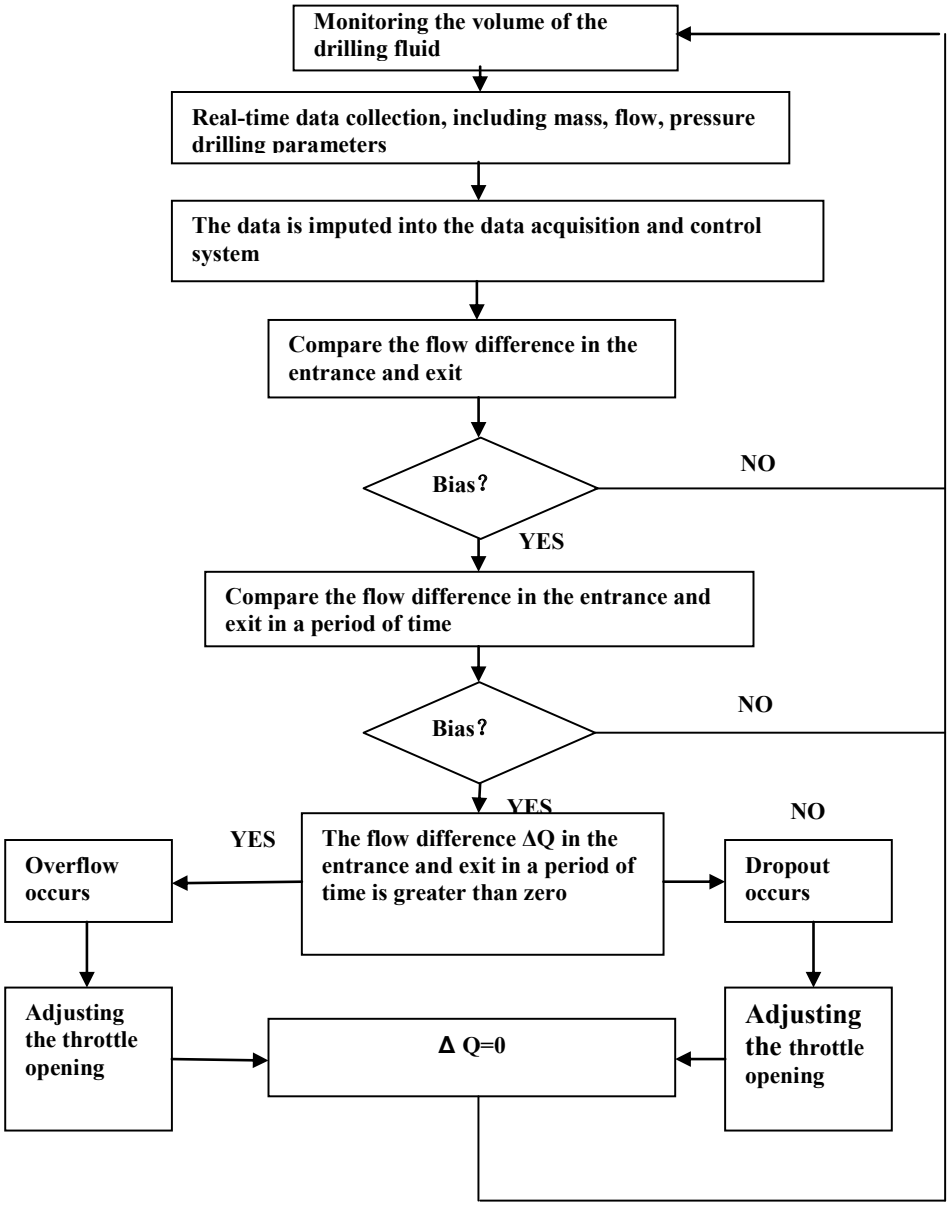

Fig.2 process of micro-flux control

Micro-flux control drilling system will be able to quickly control the drilling fluid pressure in the wellbore with simple operations on the ground. It requires continuously injecting drilling fluid In the drilling operation to balance the lateral pressure of oil, gas, water and rock to prevent borehole problems , e.g. blowouts, well collapse, pipe-

sticking and lost circulation happening[15]. Micro-flow refers to monitoring the Micro-flow of imports and Micro-flow of exports. The monitoring accuracy of the system must be very sensitive to detect very small fluctuations in the total flow of drilling fluid , so the accurate detection and control of micro- flow is the basis for the closed-loop control of the drilling fluid. During drilling operation, we have different expectations for parameters in the different drilling conditions and different well segments. The sensors collect sampled values of the drilling fluid, such as flow, pressure and temperature and convert the values to the central data acquisition and control system by analog, the control system further determines whether there is a leakage of the drilling fluid. The drilling fluid in the annulus is seen as incompressible fluid, so that slight pressure variations in the ground control unit will get quick response in the annulus. If leakage occurs, the system can determine the fracture formation and adjust the flow to reduce the back pressure to reach an balance state ; if leakage dosen't occur, the pore pressure is determined , adjusting the flow to increase the back pressure to achieve expected drilling fluid flow expected value. Throughout the drilling process, this detection and comparison will carry on. It will accomplish drilling fluid managed circulation and real-time adjust pore pressure and fracture pressure to meet the requirements of the drilling process.

2.3 BHP control method in Micro-flux control technology

BHP control method of Micro-flux control technology is different from that in convention drilling, underbalance drilling and CBHP MPD. The detail of the difference present in Table 1.

Micro-flux control technology has its advantage contrast with other drilling styles. It is not always keep the BHP constant while drilling, and allow formation fluid enter the wellhole, so it can easily to found reservoir and protect the reservoir. E.g. InTangzhong 26-H9 employ the Micro-flux control technology form well depth 4343m to 4637m. It is found 6 reservoir during the drilling, has well effect to found reservoir.[15-16]

The detection object of Micro-flux control technology is the fluid in the wellhole. It estimate the circulation system kick or loss or not by monitor and comparison the flux of enter and out the system. It assumption that gas and water two phase flow in the wellhole, theequilibrium equation of circle and annulus present below.

Table 1 The difference characteristics between drilling styles

characteristic	convention drilling	UBD	CBHP MPD	Micro-flux
Whether allow formation fluid insert?	No	Yes	No	Yes
Whether apply back pressure on wellhead?	No	Yes	Yes	Yes
Whether detective flux in entrance of system?	No	No	No	Yes
Whether detective flux in exist of system?	No	yes	Yes	Yes
Whether have realtime loss/kick detevtive	No	No	Yes	Yes
Whether maintain BHP a contest?	No	No	Yes	No(relative)

The detection object of Micro-flux control technology is the fluid in the wellhole. It estimate the circulation system kick or loss or not by monitor and comparison the flux of enter and out the system. It assumption that gas and water two phase flow in the wellhole, the equilibrium equation of circle and annulus present below.

borehole problems mostly because BHP and formation pressure has great difference. The reason of loss is due to BHP greater than fracture pressure and kick is because BHP less than formation pressure. The bottom hole pressure P_{BHP} can expression as:

$$P_{BHP} = P_{WHP} + P_H + P_L \tag{1}$$

Where :

P_{WHP} : wellhead pressure , MPa

P_H： liquid hydrostatic pressure, MPa；

P_L： friction in annulus, MPa；

When hole situation, drilling fluid performance and flux are constant, P_H and $P_L$are also stable. Only the wellhead pressure PWHP is changeable. Therefore, It can keep the BHP in a applicable range by control the back pressure in wellhead. So itcan make the drilling without kick and loss or micro-kick and micro-loss which is under control. In the operation, It can calculate the wellhead pressure by hydraulics model, with the PWD or some other downhole tools. It can measure the BHP and help the calculation and optimizing the model. Without the PWD, it also can make flux and pressure control by the law of conservation mass of drilling fluid.

First comparison transient flux of enter the system q_{in} and out of the system q_{out}t .If they are equal then go on monitor. If they have difference then calculation the flux of enter and out of the system recently to prevent the influence of the flow fluctuation which cause by mud pump water efficiency instability or something else.

Calculate the flux of enter system recently:

$$Q_{in} = \int_{t_1}^{t_2} q_{in} dt \tag{2}$$

Where, q_{in} get form the mass flow meter at the entrance of the system.

Calculation the flux of out of system recently:

$$Q_{out} = \int_{t_1}^{t_2} q_{out} dt \tag{3}$$

Where, q_{out} get form the mass flow meter at the exist of the system.

Then the difference of the flux is:

$$\Delta Q = Q_{in} - Q_{out} \tag{4}$$

Normally, the interval set as: $\Delta t = t_2 - t_1 = 1\min \sim 10\min$, according to the drilling parameter like well depth, mud pump power etc. set up the trigger value of kick and loss, are Q_L and Q_K. In the extra-deep well which well depth is over 6000 meters, to make sure the precision, set up Q_L=-Q_K=80L. Then

If

$$\Delta Q \geq Q_L \tag{5}$$

Kick occurred.

If

$$\Delta Q \leq -Q_K \tag{6}$$

loss occurred.

If

$$-Q_K < \Delta Q < Q_L \tag{7}$$

there is neither kick nor loss occurred.

According to the real time monitor, if kick occurred then increase the back pressure of the wellhead and decrease the back pressure when loss occurred. There are two ways to change the back pressure.

Linear increase/decrease the back pressure, turn on or turn off the throttle valve by proportional servo valve then change the back pressure.

$$\Delta P = K \Delta Q \tag{8}$$

Where K is a proportion coefficient which can get from experiment or experience in statistics,normally at the range of [0.01-0.1].

Text step by step

$$\Delta P = \pm(0.5MPa \sim 1MPa) \tag{9}$$

According to the reality change the back pressure a little. When loss occurred the adjustable value is negative and when kick happened the adjustable value is positive. The change value is 0.5MPa to 1MPa, get the target step by step.

Back pressure control decision by Throttle valve control module, this module's control objective is base on the result of the hydrodynamics model PBHP. According to the difference between entrance and exist of the system, estimate is there kick or loss occurred and then adjust the back pressure P_{bp}.

$$P_{bp} = P_{WHP} + \Delta P \tag{10}$$

Adjust Hydraulic throttle valve, let the back pressure approach to the P_{bp}. If the difference between P_{bp} and reading of pressure gage less then set point of the equipment's precision, normally is 0.3MPa, then adjust accomplish go monitor the flux.

3. Example

Micro-flux control technology applied in a horizontal well which location in Tazhong Xinjiang. While well depth is 5326,79 meters, detection the difference of the entrance at time 23:43, then comparison the accumulating difference recently, according to the drilling parameter set up monitor time is 1 min, kick and loss monitor precision is QL=QK=80L. From 23:43 to 23:44 accumulating difference of flux is 69.6L, do not trigger the alarm, then next minute monitor again ,the difference become 81.3L. trigger the kick alarm and decrease the throttle valve increase back pressure, like fig.6 shows, when 23:51, flux of entrance and exist equal again, kick under controlled. It is taken 8 minutes from found kick to completely controlled, totally flux is 637.2L, less than 1m³. It prove micro-flux control technology can deal with the under hole problem quickly and precisely.

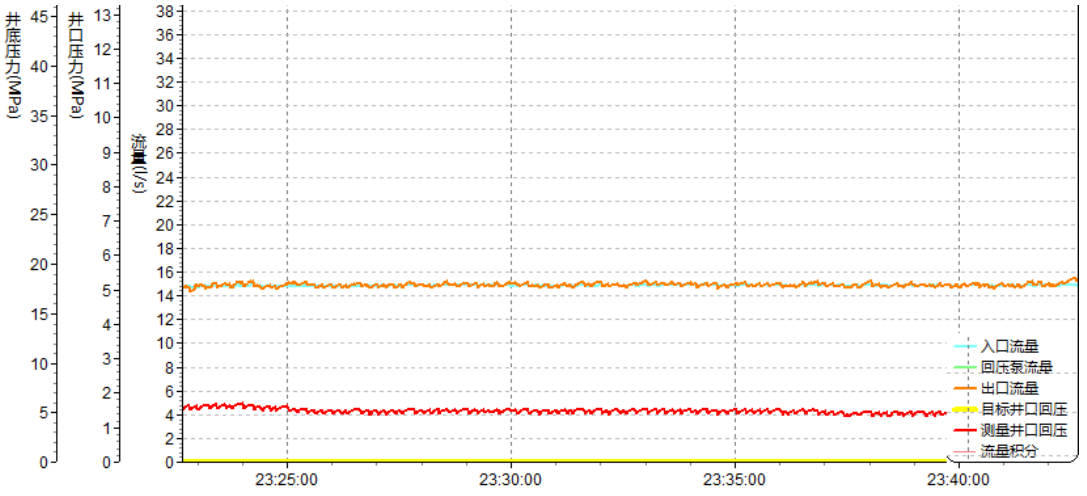

Fig. 3. Micro-flux flow monitoring Figure 1

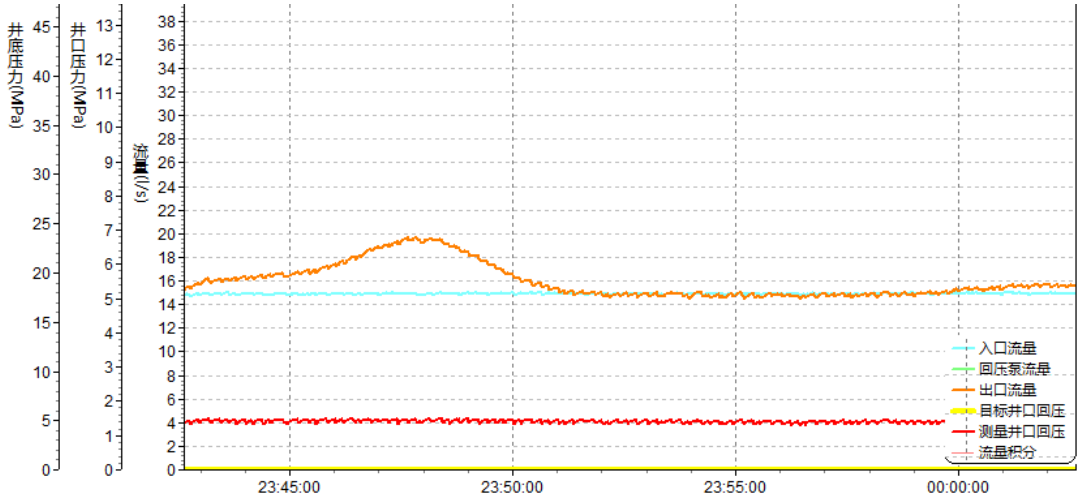

Fig. 6. Micro-flux flow monitoring Figure 2

4.Micro-flux control technology application effect innarrow window drilling

Mirco-flux control technology first application by PetroBras in August 2006. Now has been popularize all over the world. User includeWeatherford、ChevronStatoiHydro、Cypress、ENI and Total etc. and have application in onshore and offshore drilling project. Now China became a member of this technology's customer. Dagang and Sichuan oilfield completed few drilling project with Micro-flux control equipment from Weatherford and have well effect. In Dagang Bin-41 use Mirco-flux control 1070 meter, did not occurred kick or loss. Compare with well nearby, density of drilling fluid have been well controlled, average ROP promote twice, [17] resolve the narrow drilling problem in coast exploration field. Form July 1st to 20th ,2011, Mirco-flux application in Deyang-1, complete drilling, tripping, make a connection, kick monitor etc. under near balance and under balance situation, complete target successfully, operation well depth from 5303.5m to 5362m, average ROP 0.8m/h, there is no problem occurred during drilling, realize safety drilling.[18]

Moreover, The PCDS-I precision control drilling system which developed by Drilling Research Institute, CNPC have been text in Tazhong,Tarim and Jidong, both receive great success. Because of these area's reservoir fracture system developed and distribution irregular, belong to typical narrow drilling window, kick and loss occurred easily, most reservoir have H2S, drilling project have great safety risk, drilling problem include, a)It is easy to happen kick or less, belong to typical narrow drilling window, have great risk in well control. b)Reservoir fracture developed well, fractured vuggy in one. c) horizontal section drilling through multiple fractured vuggy unit, it is different to drilling, d)target reservoir have different pressure system and have H2S, have great safety risk, e) a lot problem occurred with convention drilling, have to completion with out get the target.

To solve the difficult above, it decide to use micro-flux control technology, monitor the micro-flux the while drilling curse, with the situation of do not set up PWD, the PCDS-Ⅰ measure the flux of drilling fluid into and out of the system with high precise mass flow meter. check the water power of mud pump when the flux of entrance and exist relativity stable, keep the difference between the entrance and exist are reliable. It prove that Micro-flux control technology can solve the difficult of narrow drilling window which easy to kick or loss, decrease NPT(non-production time) effective, save the drilling project time, achieve the target of advance horizontal depth and drilling safety and smoothly. The advantage of Micro-flux apportion in narrow drilling window as below.

1. Found the kick and loss quickly, mass flow meter can detection the situation of flux increase in exist of the system which cause by gas kick 5-10 minutes earlier, at this moment can not observe the change of fluid level in mud sump, so need to intensify the monitor of fluid level, calculate the change of mud sump volume

precisely, change the back pressure base on the increment of mud sump volume, avoid air column form in annular, improve effect and reliable of dislodge gas while circulate. Achieve that horizontal section drilling through multiple fractured vuggy unit, drilling safety didn't occurred any problem, didn't appear kick or loss, compare with the well nearby, control the volume of loss successfully.

2. Adjust the back pressure flexible, keep the drilling project safety, increase or decrease back pressure one make sure 15-20 minutes to observe during the MPD operation, it make sure have two times to observe the level, so can judge the down hole situation correctly, avoid the operation frequently cause borehole problem.
3. It have great effect of found reservoir, adjust back pressure of wellhead in time have well effect on found reservoir. In the situation of keep safety, adjust back pressure in time to the benefit of change flux of entrance and exist of the system and the value of gas measure in compound logging, adjust the back pressure when gas measure value increase and decrease when drilling through the reservoir, if increase again, prove that found a new reservoir. E.g. one well in Tangzhong, application Micro-flux from well depth 4343m to 4637m, found 6 reservoirs during the depth which less than 300m. have a wonderful effect of found reservoir, prove the value of Micro-flux in reservoir found.
4. Increase the ROP obviously in target. The ROP is 4.87m/h in a well location in Tazhong, average depth per day 84m, which is the 4.14 multiple of the well nearby.

5. conclusion

1. Micro-flux control technology have simple structure of control system. Only to set up sensor and dedicated choke on the rig. It can master the BHP precisely, can handle the situation like kick, loss, collapse and stuck etc. problem in drilling which cause by narrow drilling window, make drilling project safety.

2. Micro-flux can improve the ability of monitor kick and loss. Can found serious kick and loss immediately, for those not serious enough can found it in time combine with observe drilling fluid parameter on the ground, so can control the whole volume of kick and loss in a small range, reduce the risk of drilling, save cast.

3. The BHP control method of Micro-flux is different from other system of drilling. It do not maintain the BHP a constant all the time, allow formation fluid into the hole, allow the micro-kick can avoid loss effective and it is good for found and protect reservoir, have great value on geologic discovery.

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